RESEARCH ARTICLE

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Restoration of Plant Cover in Subalpine Forests Disturbed by Camping: Success of Transplanting

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ABSTRACT: Camping has severely impacted soil and vegetation in many natural areas. Effective techniques for restoring native vegetation are needed, particularly at high elevations. This study assessed the effectiveness of transplanting and restoration treatments designed to improve the physical, biological, and chemical properties of soils (scarification and amendments of organic matter, compost, and soil inoculum), and ameliorate microclimatic conditions (application of a biodegradable mulch mat) on six closed campsites in subalpine forests in Oregon. Most transplants (68%) were still alive seven years after transplanting. Mean area and height of surviving transplants increased 39% and 19%, respectively, over the seven years. Transplanting success varied among species. Graminoids survived most frequently, while tree species grew most rapidly. Only 45% of the shrub transplants survived and the canopy area of most survivors decreased. Shrubs constitute about 70% of the undisturbed groundcover. The soil amendments, particularly addition of compost and organic matter, increased the growth of transplants but had little effect on survivorship. Effects were most pronounced for graminoids and diminished after the fourth year of the experiment. The application of a biodegradable mulch mat had no effect. Transplanting locally collected plants is an effective means of accelerating the restoration of damaged campsites in these subalpine forests. However, the more elaborate treatments were only modestly successful in increasing transplanting success. They did not overcome the difficulty of restoring sustainable populations of the shrubs *Vaccinium scoparium* and *Phyllodoce empetriformis.*

Index terms: compost, ecological restoration, recreation impacts, soil amendments, wilderness

INTRODUCTION

Extensive tracts of land in the mountainous western United States have been designated as wilderness, to be preserved in a natural state. Despite their preservation mandate, wilderness lands attract legions of recreationists who enjoy hiking, riding horses, and camping overnight. Many decades of largely unregulated recreational use has resulted in severe localized site disturbance in wilderness. The subalpine zone is a common destination for wilderness recreationists, due to its scenic mix of meadow and forest, abundance of lakes, and mountain vistas. Consequently, extensive areas of subalpine forest around lakes have been disturbed, particularly by camping. Long-established campsites frequently have little remaining ground cover vegetation and contain soils that have been highly altered physically, chemically, and biologically (Cole and Fichtler 1983). Increasingly, wilderness managers in the United States are taking steps to control the location and severity of campsite impacts. A common management action is to close some highly disturbed sites, particularly those on lakeshores, to further camping. The intent of this action is to promote the recovery of native plant cover and restoration of a natural-appearing landscape.

Even with effective closure of sites to further camping disturbance, unassisted recovery of the plant cover of subalpine forests can be a slow process. Growing seasons are short and, in some regions, hot and dry. Soils are so compacted that they make poor seedbeds, and sites have been devoid of vegetation for so long that their soil has lost much of the microbial communities and nutrients that promote plant growth (Zabinski et al. 2002). In many places, the most abundant ground cover species on undisturbed sites are long-lived, clonal dwarf shrubs that seldom establish from seed (Eriksson and Fröberg 1996). Wilderness managers have often attempted to overcome these limitations to natural recovery by planting propagules, amending soils, and ameliorating microclimatic conditions. The success of these efforts is hampered by our poor understanding of: (1) the ecology of subalpine forests in general, (2) what limits recovery processes in subalpine forests, and (3) the likely effectiveness of restorative interventions.

Transplanting established plants onto disturbed sites has the potential to accelerate recovery rates substantially, particularly in subalpine plant communities where most of the ground cover consists of species that seldom reproduce sexually. Assessments of transplanting at high elevations suggest that success varies greatly, with such factors as the species being transplanted, size of the transplant, environmental characteristics of the disturbed site, and the other restoration techniques that supplement transplanting. On degraded subalpine forest campsites in Yosemite National Park, California, survival of graminoid transplants after three years was low (Moritsch and Muir 1993). Although survival exceeded 50% on some mesic sites, overall survival was only 19%. Moreover, even where most transplants survived, they did not spread and did not substantially increase the plant cover on campsites.

Other assessments of transplanting on high elevation disturbed sites (mostly conducted above timberline) have been more positive (Brown and Johnston 1979, Conlin and Ebersole 2001). Survival of transplants on machine-graded alpine ski runs in Switzerland exceeded 50% after 7-8 years, with about 50% of survivors producing seed (Urbanska 1994). Although mortality occurred even seven years after transplanting, most mortality occurred between the third and fifth year after restoration. Survival rates for plugs of *Carex exerta* MacKenzie sod, four years after being transplanted in alpine gravel, varied between 0 and 53% (Ratliff and Westfall 1992). Survival increased with plug size (5.1 cm rather than 1.9 cm) and decreased with application of an inorganic fertilizer. On high elevation ski runs in Scotland, all transplanted turfs were alive after four years, but they had not spread and the addition of fertilizer made little difference to turf size (Bayfield 1980). In alpine tundra in Colorado, transplant survival after one year varied among six species (17-98%) and among six microenvironments (44-83%). Survival was greatest for graminoids with fibrous roots and no rhizomes; survival was also greatest on sites with high soil moisture and with long-lasting snow cover (May et al. 1982). Eighteen years after sod transplants were used to revegetate an alpine pipeline disturbance in Colorado, visual evidence of disturbance was minimal in most plant communities (Buckner and Marr 1990); vegetation cover was still reduced in the community dominated by the dwarf shrub *Vaccinium scoparium* Leiberg.

Given the mixed results regarding transplanting success and the paucity of studies in subalpine plant communities, we experimented with various restoration techniques on long-disturbed campsites adjacent to subalpine lakes in a wilderness in the northwestern United States. Specifically, we assessed the effectiveness of transplanting locally-collected established plants onto campsites, improving the physical, biological, and chemical properties of soils (through scarification and amendments of organic matter, compost, and soil inoculum), and ameliorating microclimatic conditions (though application of a biodegradable mulch mat) over a seven-year period. We focused on the transplanting of established plants, because the most abundant ground cover species on these campsites are dwarf shrubs that seldom reproduce from seed, *Vaccinium scoparium* Leiberg and *Phyllodoce empetriformis* (Sw.) D. Don.

METHODS

Study Sites

This study was conducted in the Eagle Cap Wilderness, Wallowa Mountains, northeastern Oregon, on six campsites that had been selected for restoration. Sites were located at an elevation of 2215-2300 m, adjacent to subalpine lakes, and are only accessible on foot or horseback (12-15 km from the closest road). The campsites were all located within 4 km of each other, at five different lakes. All sites were located in forests with an overstory of *Abies lasiocarpa* (Hook.) Nutt., *Pinus contorta* Dougl., and *Pinus albicaulis* Engelm. Ground cover vegetation on adjacent, little-disturbed sites is discontinuous. Ericaceous dwarf shrubs (*Vaccinium scoparium* and *Phyllodoce empetriformis*) and caespitose graminoids (*Juncus parryi* Engelm. and *Carex rossii* Boott) are the most abundant species. This plant community type is widespread throughout much of the western United States at high elevations, particularly in locations that are popular destinations for wilderness recreation. Consequently, the impacts of wilderness camping are probably more common in this community type than any other in the United States, thus making information about effective restoration techniques particularly useful. Soils are shallow, sandy, and acidic (pH between 4.2 and 4.8), derived from granitic substrates (Cryochrepts and Cryorthents). Although snow typically covers the ground until late June/early July, snowmelt is typically followed by hot, dry summers. Consequently, soils can be highly droughty for several months (most of the growing season).

These campsites have probably exhibited high levels of impact (lack of vegetation, minimal soil organic horizons, and compacted mineral soil) for at least 50 years. Prior to restoration, these campsites were typically about 200 m^2 in size, with about 100 m^2 completely devoid of vegetation. Soil organic horizons had eroded away over substantial portions of these sites, and mineral soils were so compacted that infiltration rates were reduced by almost 50% (Cole and Fichtler 1983). Potentially mineralizable N and microbial activity were also substantially reduced on these campsites (Zabinski et al. 2002).

Design and treatments

Campsite restoration began in the summer of 1995. Sites were closed to recreation use (using ropes and closure signs) and soils were scarified. Hand kneading and implements (e.g., shovels and hoes) were used to break up soil compaction and clods, producing a crumb texture, to a depth of about 15 cm. At the end of the growing season (September), transplanting occurred on six 1.5-m x 1.5-m plots on each of the six campsites. Where possible, plots were located adjacent to each other rather than being distributed across the entire campsite. A split plot experimental design was established. Half of the treatment plots (three) were covered with a biodegradable mulch mat made of straw interwoven with cotton string and jute (Bionet ®); half were not.

Within each mulch treatment (the mulched plots and those without mulch), each of the three treatment plots was randomly assigned one of three levels of soil amendments. One plot received no soil amendments. One plot was amended with organic material and inoculated with native soil. A 2.5 cm deep layer of locally collected, well-decomposed organic matter (mostly from the needles, twigs, and boles of coniferous trees), supplemented with dry peat moss mixed with water, was mixed into the mineral soil to a depth of 7.5 cm. Native soil inoculum came from the rooting zone of local transplants that were being transplanted onto the site. About 1.2 L of soil was mixed with about 20 L of water to make a slurry. Three liters of slurry were sprinkled over each plot and raked into the soil. One plot was amended with organic matter and soil inoculum (administered as on the other plots), supplemented with a compost treatment. A 2.5-cm layer of compost (sewage sludge/log yard waste compost with a C:N of approximately 20:1; Eko Compost®, Missoula, Montana) was raked into the top 10 cm of soil.

Transplants (mostly 5-25 cm in diameter) were excavated from patches of undisturbed, mature vegetation, close to the campsites. Depending on the species, transplant plugs consisted of one large individual or many smaller individuals. Each plot in each campsite received an equal number of transplant plugs of identical dominant species of approximately the same size. The number of plugs per plot varied among campsites (from five to seven plugs), as did the intentionally transplanted species. *Vaccinium scoparium* and *Juncus parryi* were intentionally transplanted on five of six campsites. *Phyllodoce empetriformis* and *Carex rossii* were intentionally transplanted on three campsites. Species that were intentionally transplanted on only one or two campsites were: *Luzula hitchcockii* Hamet-Ahti, *Sibbaldia procumbens* L., *Danthonia intermedia* Vasey, *Antennaria lanata* (Hook.) Greene, *Antennaria alpina* (L.) Gaertn., *Aster alpigenus* (T.&G.) Gray, *Achillea millefolium* L., *Hypericum formosum* H.B.K. , *Pinus contorta, Calamagrostis canadensis* (Michx.) Beauv., *Spiraea betulifolia* Pall., *Polemonium pulcherrimum* Hook., *Oryzopsis exigua* Thurb., and *Abies lasiocarpa.* Thirteen other species were unintentionally included in plugs. The trees were young seedlings (mean height of about 15 cm); most of the transplanted shrubs and herbaceous plants were probably mature. Nomenclature follows Hitchcock and Cronquist (1973).

Transplant plugs were all planted in the central 1-m^2 portion of each treatment plot, leaving a 0.5 m buffer between treatments. Immediately after transplanting, transplants typically occupied about 10% of each plot (compared to ~60% vegetation cover on undisturbed sites). As they were being planted, transplants were given about 0.6 L of water. During the 1996 growing season, transplants were watered three times, when it appeared that soils were dry. When this was done, all plots were given an equal amount of water (about 0.6 L). No supplemental watering was done in any of the later years.

Measurements

For each transplant, we estimated area of canopy cover, using a 1-m square quadrat with a 5-cm x 5-cm grid. We also measured the maximum height of each transplant and, starting three years after transplanting, noted whether it had flowered that year. Where there were multiple species in a plug, the area of each species was measured separately. We did not attempt to distinguish between multiple individuals of the same species in the same plug, but we had no reason to believe that number of individuals varied substantially among plugs. Measurements were taken immediately after transplanting (September 1995), as well as in September of each successive year through 2002.

Data Analysis

From our field measurements, change over time was assessed for five response variables: (1) transplant survival, (2) transplant flowering, (3) mean plug area, (4) mean maximum transplant height, and (5) total transplant area. Survivorship curves for individual transplants, as well as the proportion of surviving transplants per plot, were calculated. Transplant flowering was assessed as the proportion of live transplants in each plot that flowered that year. Mean plug area provides a means of assessing the horizontal growth (or contraction) of transplants. It is the mean area of all plugs in a plot that survived to the end of the experiment, with plug area being the sum of areas of all transplants in a plug. Mean maximum transplant height, which relates to vertical growth (or contraction) of transplants, is derived from measures of the maximum height of vegetative parts for the tallest transplant in each plug. It is the mean maximum height for all plugs that survived to the end of the experiment. Total transplant area, the sum of the areas of all transplants on a plot, varies with both survival and mean plug area. These final three metrics (mean plug area, mean maximum transplant height, and total transplant area) varied immediately after transplanting. To factor out this unintentional variation, we calculated change in each of these variables by subtracting the original (1995) value from subsequent values.

Given the relatively low power of statistical tests based on six replicates, we did not define an arbitrary fixed alpha level as a basis for concluding whether treatments had a statistically significant effect. Instead, we report the magnitude of treatment effects, using output from statistical analyses to describe the precision of effect size estimates. This allows us to comment on how confident we are in concluding that observed differences are the result of treatments rather than chance.

For each response variable other than survival, we performed repeated measures analyses of variance, appropriate for split-plot designs, using PROC MIXED in SAS 9.1 (Littell et al. 1996). We used the Akaike Information Criterion to identify the covariance structures that best fit the data. Analyses suggested that violations of the assumptions for these tests were not sufficient to require transformation of variables. From these analyses, we drew conclusions about whether or not variables differed substantially over the seven-year period of study. Evidence for positive effects of soil amendment and mulch treatments was assessed using one-tailed post-hoc Tukey-Kramer tests, adjusted for multiple comparisons. Estimates of the magnitude of treatment effects and the precision of these estimates are provided in tables of means and confidence intervals (Dunnett's adjusted) for the difference between treated and unamended plots for each year of the experiment (Di Stefano 2004). Life table analysis (Fox 1993) was conducted to produce survivorship curves. PROC LIFETEST in SAS 9.1 was used to generate Wilcoxon chi-squares for overall analyses as well as the output needed to develop Z-statistics enabling comparisons among treatments, as outlined in Fox (1993).

RESULTS

None of the five response variables differed substantially or consistently depending on the presence or absence of a mulch treatment (repeated measures ANOVA, $p = 0.37$ to 0.47). Moreover, the effect of the mulch treatment did not interact significantly with the soil treatments. Consequently, the description of results that follows will focus on overall results and the effect of different soil treatments. When the effects of different soil treatments are described, data from plots with and without the mulch treatment are pooled.

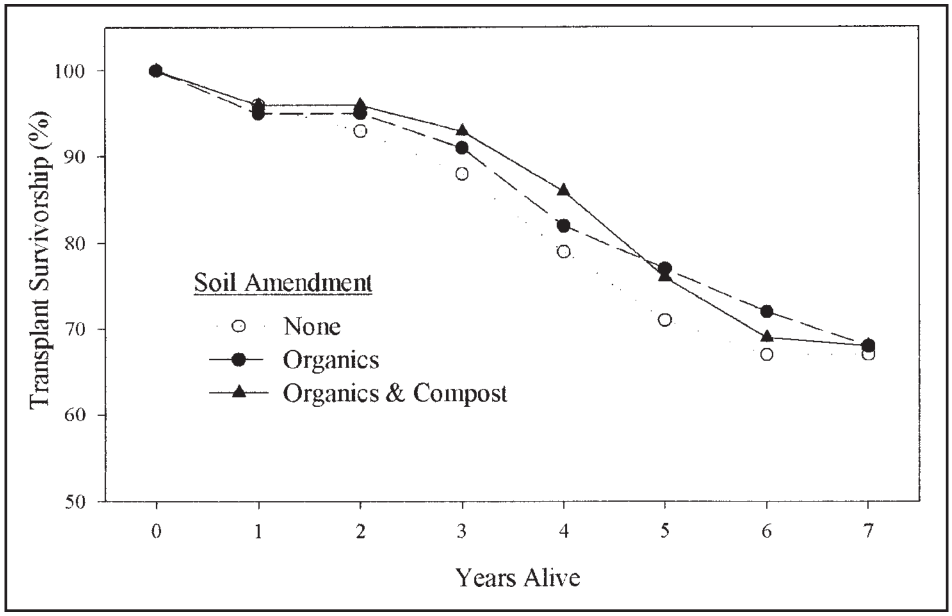

Figure 1. Percent survivorship of transplants on plots receiving different soil treatments.

Transplant Survival

Most plants (68%) were still alive seven years after being transplanted onto the campsites. Mortality occurred every year of the experiment but rates were highest (7-9% mortality per year) in the fourth, fifth, and sixth years after planting (Figure1). Informal observations suggest variation among years was related to variation in soil moisture during the summer. For the first three years of the experiment, summers were moist and cool and/or the snowpack lasted late into the summer. Moreover, in the first year, transplants were watered during periods without precipitation. During the fourth, fifth, and sixth years, the snow pack disappeared earlier and summers were hot and dry. The final year, snowpack and summer precipitation were average; summer temperatures were cool. Soil treatment did not affect survivorship much either over the entire seven years of the experiment (Wilcoxon chi-square = 0.23, $df = 2$, $p = 0.89$) or in 2002 (Pearson chi-square = 0.14, $df = 2$, $p = 0.93$).

Transplant Growth and Flowering

To assess transplant growth, analysis was confined to transplants that were still alive in 2002. For these plants, area of canopy cover increased 39% over the seven-year period of the experiment, from a mean of 165 cm^2/plot to a mean of 230 cm^2/plot (Figure 2). The magnitude of increase varied substantially among years (repeated measures ANOVA, $F = 8.47$, $df = 6$, $p < 0.001$). Mean plug area increased each year for the first four years, to a maximum of 292 cm^2 (77% larger than in 1995), and declined each year thereafter.

Between 1995 and 2002, plug area increased 29 cm^2 (18%) on unamended plots, 68 cm^2 (43%) on organics plots, and 83 cm^2 (47%) on compost and organics plots. The magnitude of soil amendment effect increased each year for the first four years following transplanting; by 1999, mean plug area on plots treated with compost and organics was 142 cm^2 (70%) larger than mean plug area on unamended plots (Table 1). This soil amendment effect declined each year thereafter. By 2002, the mean

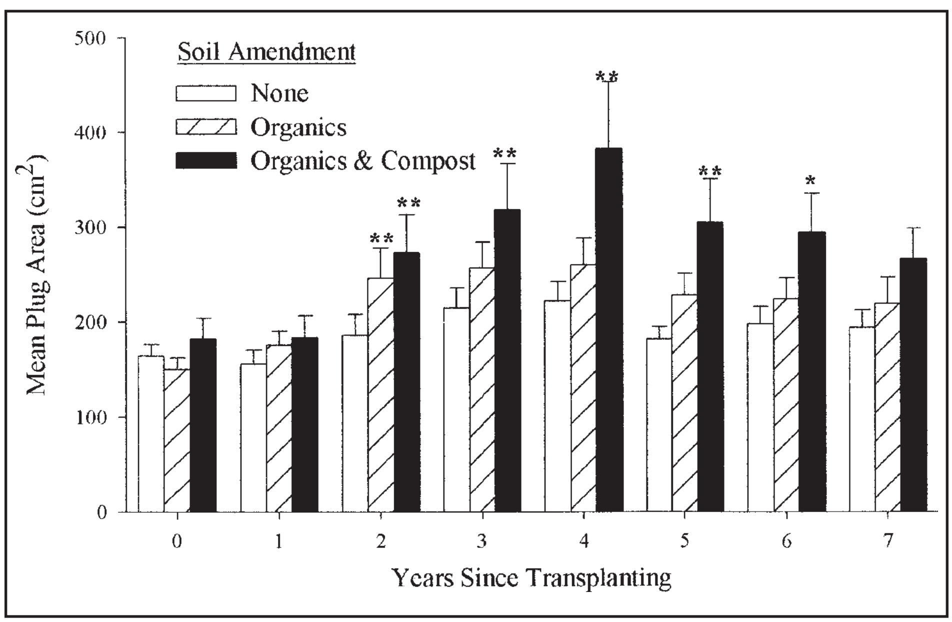

Figure 2. Mean area (and SE) of the transplanted plugs that survived at least seven years. Soil treatments that differ significantly from unamended plots are denoted by ** ($p \leq 0.05$) and * ($p \leq 0.1$).

Table 1. Effect of soil treatment on mean plug area/plot by year.[1]

	Organics		Compost/Organics	
Year	Mean (cm^2)	Limit (cm^2)	Mean (cm^2)	Limit (cm^2)
1996	34	-6	10	-31
1997	74	14	69	8
1998	57	-30	85	1
1999	52	-38	142	36
2000	69	-32	104	12
2001	41	-47	79	-9
2002	40	-35	55	-20

[1] Values are the difference between amended and unamended soil treatments, in cm^2. Both the mean and the lower 95% confidence limit for this difference are shown. A negative lower limit suggests lack of statistical significance at 0.05.

difference was only 55 cm^2 (28%).

Transplants expanded vertically, as well as horizontally, but to a lesser degree. The mean maximum height of the tallest plant, in plugs still alive in 2002, increased 19%, from 11.5 cm to 13.7 cm. Magnitude of increase in height varied substantially among years (repeated measures ANOVA, $F = 31.28$, $df = 964$, $p < 0.001$). Mean maximum height increased most in the second and third years following transplanting (to a maximum of 17 cm in 1998) and generally declined thereafter (Figure 3). Magnitude of increase did not vary substantially or consistently with soil amendments (repeated measures ANOVA, $F = 0.22$, $df = 20$, $p = 0.80$).

The proportion of transplants that flowered was first recorded two years after transplanting. This proportion varied substantially among years (repeated measures ANOVA, $F = 10.56$, $df = 147$, $p < 0.001$), but not among soil treatments (repeated measures ANOVA, $F = 0.22$, $df = 20$, $p = 0.80$) (Figure 4).

Total Area of Transplants

The growth of transplants that survived did not entirely offset the mortality of those plants that did not survive. Consequently, total transplant area declined 5% from a mean of 1003 cm^2/plot immediately following transplanting to a mean of 952 cm^2/plot seven years later. The magnitude of change in total area varied substantially among years (repeated measures ANOVA, $F = 4.99$, $df = 6$, $p < 0.001$). Total area decreased slightly the first year after transplanting and then increased for two years to a maximum of 1275 cm^2/plot in 1998. It decreased each year thereafter.

Both these temporal patterns and the magnitude of change varied with soil treatment (Figure 5). On unamended plots, transplant area declined 19% from a mean of 956 cm^2/plot immediately after transplanting (1995) to a mean of 772 cm^2/plot seven years later (2002). Only in the second and third years did transplant area increase and only after the third year did transplant area exceed its original (1995) value. On plots with soils amended with organics, transplant area declined 15% from a mean of 1067 cm^2/plot in 1995 to a mean of 905 cm^2/plot in 2002. Although transplant area only increased for the first two years following transplanting, transplant area exceeded its original (1995) value until the fifth year following transplanting. On plots with soils amended with compost and organics, transplant area increased 12% from a mean of 998 cm^2/plot in 1995 to a mean of 1121 cm^2/plot in 2002. Transplant area increased during the second through fourth years following trampling, reaching a maximum of 1636 cm^2/plot in 1999, but declined each year thereafter.

The total area of transplants increased more on plots amended with compost and organics than on unamended plots ($t = 2.19$, $df = 20$, $p = 0.05$). The magnitude of soil amendment effect increased each year for the first four years following transplanting; by 1999, mean total transplant area on plots

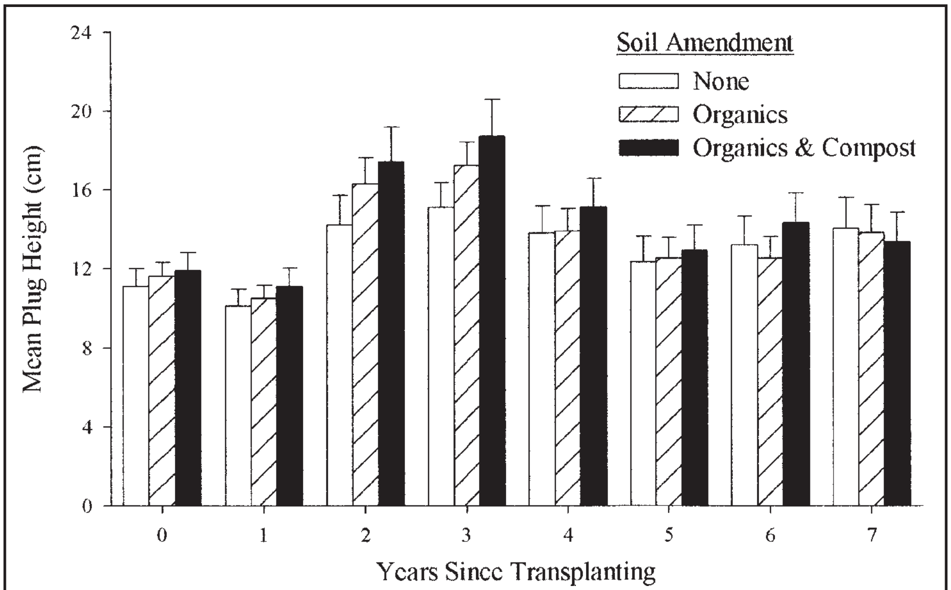

Figure 3. Mean height (and SE) of transplants in plugs that survived at least seven years, on plots receiving different soil treatments.

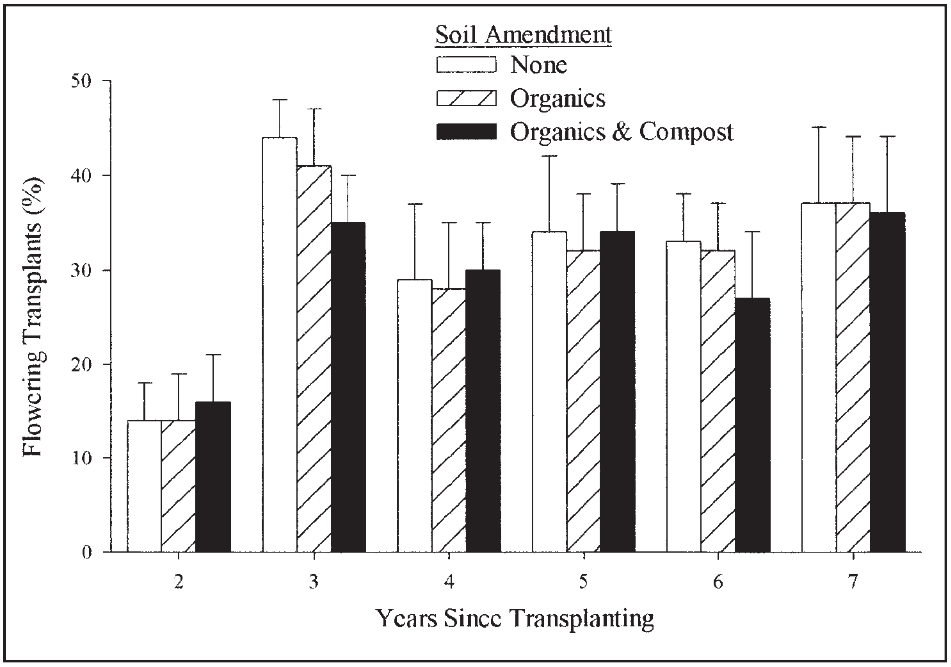

Figure 4. Mean percent (and SE) of transplants that flowered, for those that survived at least seven years, on plots receiving different soil treatments.

treated with compost and organics was 677 cm^2 (75%) larger than on unamended plots (Table 2). This soil amendment effect declined each year thereafter. By 2002, the mean difference was only 306 cm^2 (40%). Although increases in total transplant area were greater on plots amended with organics than on plots without soil amendments (Table 2), variability in response makes it difficult to conclude with much confidence that the organics soil treatment had a positive effect on transplant area (Tukey-Kramer multiple comparison test, $t = 0.59$, $df = 20$, $p = 0.41$).

Response of Individual Species

Individual species responded variably to transplanting (Table 3). Survivorship typically varied between 40% and 100%, although none of the seven *Achillea millefolium* transplants survived. The transplants of some species consistently grew in area and/or height; transplants of other species did not. Of the 19 intentionally planted species that survived to 2002, nine species increased substantially (>20%) in area, as much as 7-fold in the case of *Pinus contorta* (Table 3). Six species decreased substantially in area. Height increased substantially for six species and decreased substantially for six species. The proportion of plants that flowered varied among species and years. For most species, maximum flowering occurred in 1998, three years after transplanting.

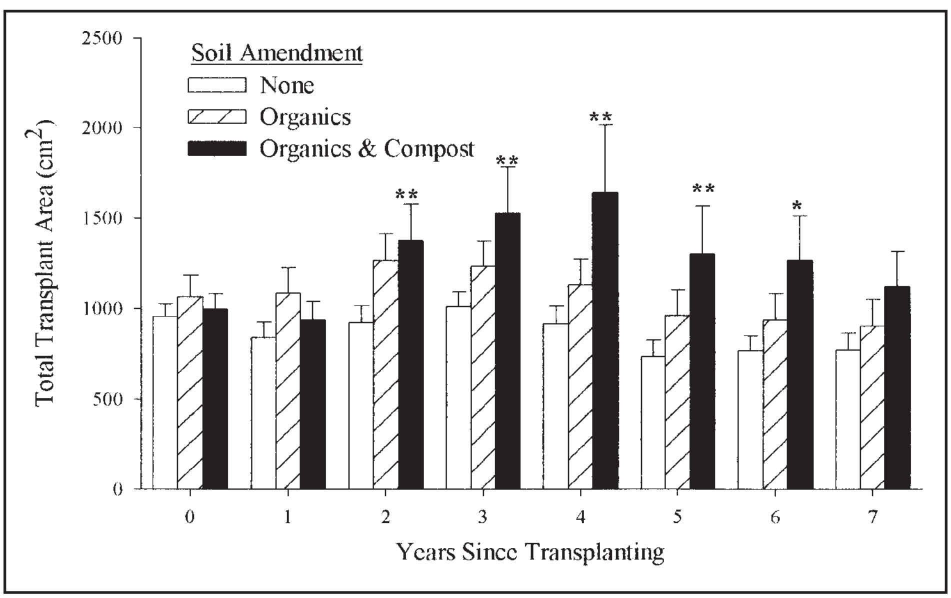

Figure 5. Total area (and SE) of transplants on each plot. Soil treatments that differ significantly from unamended plots are denoted by ** (p ≤ 0.05) and * (p ≤ 0.1).

For four species, we assessed the effect of soil treatment on survivorship and growth. The two most abundant species in the understory vegetation of undisturbed sites adjacent to these campsites were *Vaccinium scoparium* and *Phyllodoce empetriformis*. These low-growing shrubs transplanted less successfully than most species. Only 45% of *V. scoparium* transplants survived, and those that did survive decreased in area and height. Consequently, the total area of *V. scoparium* transplants declined 62% in seven years. Fifty percent of the *P. empetriformis* transplants survived. Although those plants that survived until 2002 increased in area and height, total area of *P. empetriformis* transplants declined 62% because the larger transplants did not survive.

Soil amendments had little effect on the transplanting success of *P. empetriformis.* In the case of *V. scoparium* transplants, soil amendments affected transplant survival but not growth (Figure 6). Although differences between treatments were not substantial when the entire length of the experiment is examined (Wilcoxon chi-square = 2.37, $df = 2$, $p = 0.15$), survival was substantially greater on plots that received either of the soil amendment treatments, starting with the fourth year following transplanting. They remained substantial at the end of the experiment in 2002 (Pearson chi-square = 4.62, $df = 2$, $p = 0.05$). One possible explanation for this result is that soil amendments promoted survival during summers when

Table 2. Effect of soil treatment on total transplant area/plot by year.[1]

Year	Organics Mean (cm^2)	Organics Limit (cm^2)	Compost/Organics Mean (cm^2)	Compost/Organics Limit (cm^2)
1996	136	-23	55	-104
1997	233	-53	411	125
1998	114	-314	475	47
1999	102	-437	677	138
2000	115	-321	524	87
2001	56	-364	457	36
2002	22	-340	306	-56

[1] Values are the difference between amended and unamended soil treatments, in cm^2. Both the mean and the lower 95% confidence limit for this difference are shown. A negative lower limit suggests lack of statistical significance at 0.05.

soil moisture was more limiting.

For the two other species, soil amendments influenced the magnitude of plant growth but not survivorship. In contrast to the shrubs, the two most abundant graminoids, *Juncus parryi* and *Carex rossii*, transplanted quite successfully. All transplants of these two species survived, regardless of treatment. Transplants also increased substantially in both area and height (Table 3). The area of *C. rossii* transplants increased more on plots with compost and organic amendments than on unamended plots (Tukey-Kramer multiple comparison test, $t = 3.61$, $df = 123$, $p = 0.001$) or on plots treated with only organics (Tukey-Kramer multiple comparison test, $t = 2.08$, $df = 123$, $p = 0.05$) (Figure 7). The soil amendment effect was most pronounced in the third through sixth years after transplanting.

Table 3. Responses of individual species.

Species	Number	Survival (%)	Survivor Area (cm^2) 1995	Survivor Area (cm^2) 2002	Survivor Height (cm) 1995	Survivor Height (cm) 2002	Flowering (%) Max	Flowering (%) 2002
Abies lasiocarpa	8	63	66	121	12	18.8	0	0
Achillea millefolium	7	0	-	-	-	-	14	-
Antennaria alpina	8	50	117	41	6.3	1	13	0
Antennaria lanata	13	92	90	80	6	3.6	39	15
Aster alpigenus	8	100	76	19	4.9	3.6	13	0
Calamagrostis canadensis	7	86	144	142	20.1	22.2	57	0
Carex rossii	21	100	122	223	8.8	10.5	60	5
Danthonia intermedia	9	89	123	57	15.2	8.7	100	67
Deschampsia caespitosa	1	100	135	217	10	10.5	100	100
Festuca viridula	5	80	141	155	13.8	16.3	40	0
Hypericum formosum	8	50	174	46	10.3	4	13	0
Juncus parryi	40	100	199	278	14	17.8	95	95
Luzula hitchcockii	17	47	173	238	9.8	9.2	19	0
Oryzopsis exigua	6	100	227	98	17.8	10.9	83	33
Phyllodoce empetriformis	16	50	154	235	10.8	12.5	44	19
Pinus contorta	6	100	66	471	18.7	47.5	0	0
Polymonium pulcherrimum	6	83	64	164	3	8.5	17	0
Sibbaldia procumbens	18	89	125	220	2.9	3.6	89	61
Spiraea betulifolia	7	43	50	30	9.3	6.1	0	0
Vaccinium scoparium	69	45	135	114	12.1	10.6	1	1

Increase in height also varied substantially among soil treatments. Increases were greater on both compost and organic plots than on unamended plots, although confidence in the positive influence of the compost and organic amendments (Tukey-Kramer multiple comparison test, $t = 2.30$, $df = 123$, $p = 0.03$) exceeds confidence in the positive influence of the organic amendments (Tukey-Kramer multiple comparison test, $t = 1.97$, $df = 123$, $p = 0.06$). Frequency of flowering did not vary with soil treatment.

The area of *J. parryi* transplants increased more on plots with either of the soil amendments than on unamended plots (Tukey-Kramer multiple comparison test, $t = 2.16\text{-}2.61$, $df = 255$, $p = 0.01\text{-}0.04$). Differences were most substantial in the second through fifth years following transplanting (Figure 8). Neither increase in height nor frequency of flowering varied much with soil treatment.

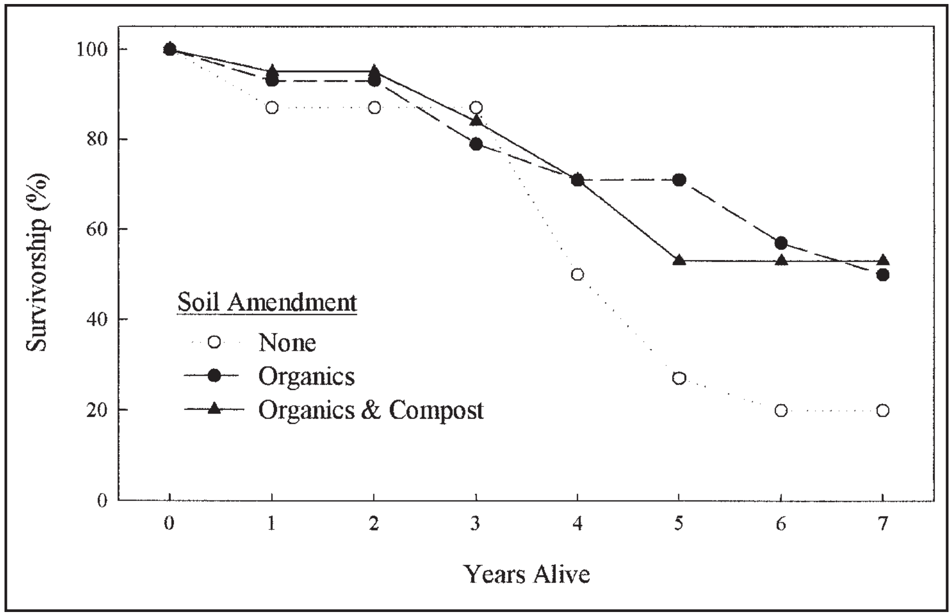

Figure 6. Percent survivorship of *Vaccinium scoparium* transplants on plots receiving different soil treatments.

Response of Growth Forms

To further explore variation in response, species were classified by growth form. Survivorship varied substantially among growth forms (trees, shrubs, forbs, and graminoids) (Pearsons chi-square = 41.9, $df = 3$, $p < 0.001$). Graminoids were most likely to survive transplanting, while shrubs were least likely to survive (Table 4). Survivorship did not vary substantially with soil treatment for any of these growth forms.

Transplanted trees that were still alive in 2002 grew more than transplants of other growth forms, both in area and height (Table 4). All 10 surviving trees increased in both area and height. Mean area and height increased for graminoid transplants, although 35% of graminoid transplants decreased in area and 30% decreased in height. Mean area and height also increased for forbs, although 37% of forb transplants decreased in area and 37% decreased in height. Mean area and height decreased for shrub transplants; 50% of shrub transplants decreased in area and 45% decreased in height. Consequently, change in total area of transplants was lower for shrubs than for any of the other growth forms (Tukey-Kramer multiple comparisons, $t = 3.61\text{-}5.69$, $df = 304$, $p < 0.002$) (Table 4). Shrub transplant area declined 63% from 1995 to 2002.

As was the case with survivorship, increase in height did not vary substantially with soil treatment for any of the growth forms. For graminoids, the area of surviving transplants increased more, between 1995 and 2002, on plots with compost and organic amendments than on unamended plots (Tukey-Kramer multiple comparisons, $t = 2.75$, $df = 93$, $p = 0.01$). For other growth forms, differences among soil treatments were neither substantial nor consistent.

As Table 5 indicates, soil amendments did not have a positive effect on the total area

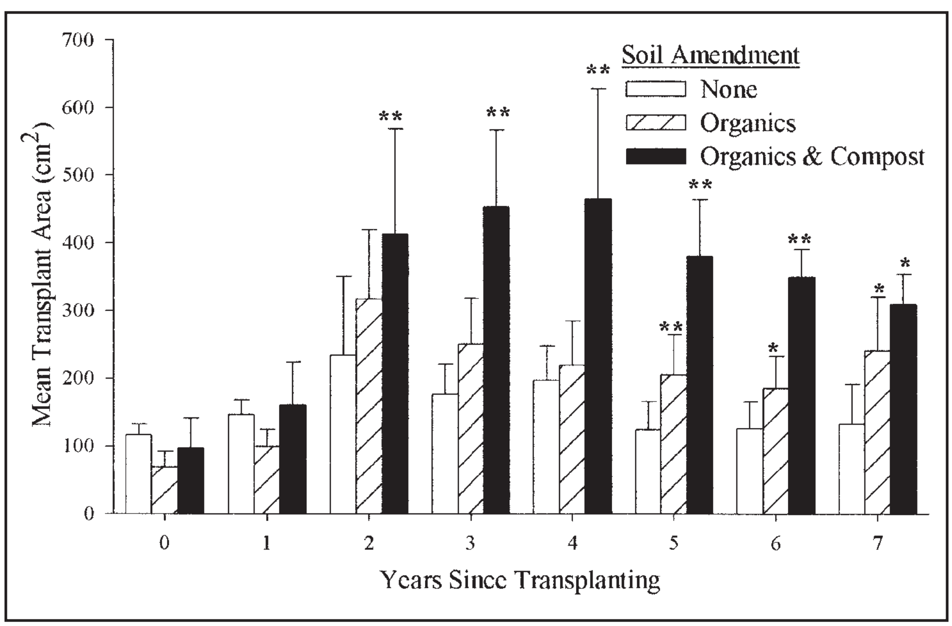

Figure 7. Mean area (and SE) of *Carex rossii* transplants. Soil treatments that differ significantly from unamended plots are denoted by ** ($p \leq 0.05$) and * ($p \leq 0.1$).

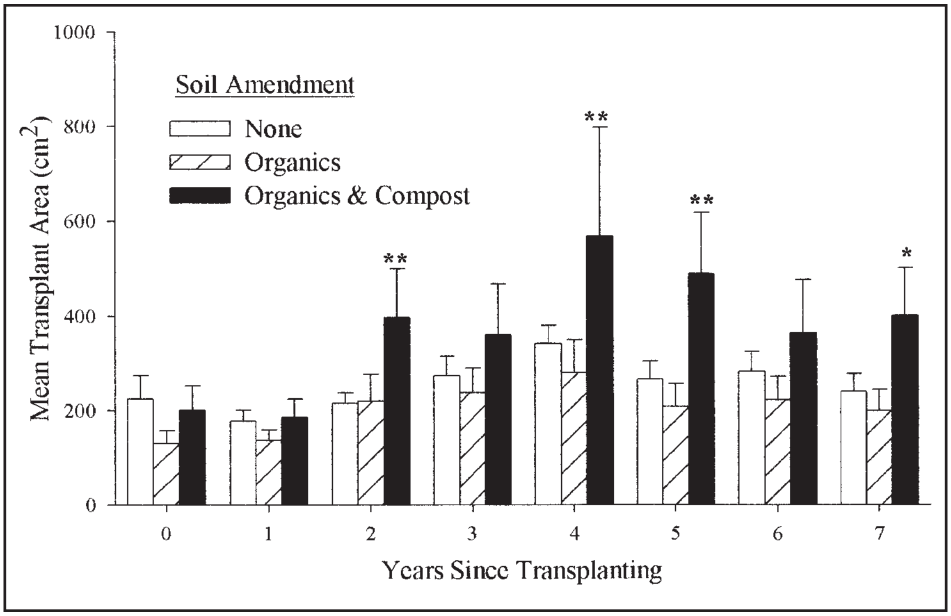

Figure 8. Mean area (and SE) of *Juncus parryi* transplants. Soil treatments that differ significantly from unamended plots are denoted by ** ($p \leq 0.05$) and * ($p \leq 0.1$).

of tree or shrub transplants in 2002. They did have a positive effect on total area of forbs and graminoids. However, only in the case of graminoids can we confidently conclude that observed effects are the result of treatments rather than chance. Between 1995 and 2002, mean area of graminoids decreased 11% on unamended plots. It increased 29% on organic plots and increased 51% on compost and organic plots.

DISCUSSION

Transplanting established plants was quite successful at reestablishing vegetation on severely impacted campsites in these subalpine forests. The 68% survival rate of transplants, after seven years, is much greater than was reported for subalpine campsites in Yosemite National Park (Moritsch and Muir 1993); it is more comparable to survival rates of 54-88%, twelve years after transplanting ski runs in the Alps (Fattorini 2001). Overall, the total area of transplant canopy declined only 5% over the seven-year period. Portions of these campsites that were not planted remained virtually devoid of vegetation at the end of the experiment.

Transplanting success varied among growth forms and individual species, however. Most transplanted trees survived and grew rapidly. Our finding of particularly high growth rates for trees is not surprising considering that these plants were only a few years old; most transplants of other growth forms were mature individuals that may already have reached near-maximum size. Most forbs survived and most grew, although growth rates were less pronounced than for trees. Graminoid survivorship was very high and most of the transplanted plugs expanded, particularly in area. Growth rates were typically intermediate between those of trees and those of forbs. Other studies commonly report particular success with transplanting graminoids (Brown and Johnston 1979, Conlin and Ebersole 2001).

The only graminoid with low survivorship, *Luzula hitchcockii*, is rhizomatous. This result is consistent with the finding of May et al. (1982) that survivorship is greatest among graminoids with fibrous roots and without rhizomes. It is more difficult to generalize about characteristics that differentiate forbs that transplanted well from forbs that did not. The complete mortality of *Achillea millefolium* was unexpected, since this species is often a weedy colonizer of disturbances. However, the campsite on which *A. millefolium* was planted had particularly shallow soils, prone to desiccation, and was one of the two campsites on which most transplants did poorly. Forb transplants tended to survive better when they were intermixed

Table 4. Variation in transplanting response among growth forms.[1]

	Growth Form			
Response Parameter	Tree	Shrub	Forb	Graminoid
Survival (%)	79	45	72	87
Change in Area of Survivors (cm^2)	243^a	0^b	29^b	56^b
Change in Height of Survivors (cm)	19.1^a	-0.7^c	1.1^{bc}	3.0^b
Change in Total Transplant Area (cm^2)	157^a	-97^c	-5^b	41^b

[1] Values are means. Survival varies significantly among growth forms ($\chi^2 = 41.9$, $df = 3$, $p < 0.001$). Means with different letter superscripts differ significantly from each other (ANOVA, Tukey-Kramer multiple comparisons, $p < 0.05$).

Table 5. Variation in effect of soil treatment on total transplant area/plot by growth form.[1]

		Organics		Compost/Organics	
Growth Form	N	Mean (cm^2)	Limit (cm^2)	Mean (cm^2)	Limit (cm^2)
Trees	14	-153	-598	-118	-525
Shrubs	93	-84	-194	-3	-104
Forbs	90	16	-41	33	-27
Graminoids	111	70	1	107	37

[1] Values are the difference between amended and unamended soil treatments, in cm^2. Both the mean and the lower 95% confidence limit for this difference are shown. Positive means indicate positive effect of treatment. A negative lower limit suggests lack of statistical significance at 0.05.

with shrubs or graminoids. The two forbs that were most successfully transplanted as complete plugs, *Sibbaldia procumbens* and *Polemonium pulcherrimum*, have stout rhizomes or a woody caudex.

In contrast, less than half of the transplanted shrubs survived; half of those that did survive decreased in area, and those that expanded did not grow much. Consequently, the total area of shrub transplants declined 63%. This poor success is problematic because shrubs are the dominant groundcover species in these forests. In the undisturbed forest adjacent to these campsites, *Vaccinium scoparium* typically constitutes about 55% of the cover, with *Phyllodoce empetriformis* contributing another 15%. The problem of poor transplanting success is compounded by the fact that these shrubs seldom reproduce by seed. The challenge to restoration of these sites is largely a matter of restoring sustainable populations of these two ericaceous shrubs. Perhaps the solution is simply to plant these species at high densities, expecting most plants to die. However, this raises concerns about appropriate sources of plant material. Particularly if many plants are required, they should generally be propagated in nurseries rather than collected from undisturbed places (Urbanska 1994). The only non-ericaceous shrub that was transplanted, *Spiraea betulifolia,* also had high mortality and grew poorly.

Transplanting success was increased by amending soils, particularly when both compost and organics were added to soil, but the benefits gained were modest. As described in more detail in Zabinski et al. (2002), the compost and organic amendments increased total carbon, potentially mineralizable nitrogen, microbial carbon utilization profiles, microbial biomass C, and basal respiration in soils. Organic amendments probably also increased the water-holding capacity of these soils, decreased their susceptibility to compaction, and inoculated soils with native microorganisms (although these likely effects were not directly measured). For most species, the positive effect of soil amendments was an increase in growth rather than an increase in survival. On plots that received compost and organic amendments, total transplant area increased 12% between 1995 and 2002. These results are consistent with studies from other ecosystem types reporting positive effects of soil compost on plant growth (e.g., Caravaca et al. 2002). In contrast, studies report that inorganic fertilizers can be detrimental to the growth of plants at high elevations (Ratliff and Westfall 1992).

The positive effect of soil amendments on transplant growth was most pronounced for graminoids. The soil amendments did not have a positive effect on the growth of the shrub species that are such a challenge to grow. Petersen et al. (2004), working in forests at similar elevations but below the subalpine zone in the southwestern United States, also report minimal differential response of shrub species to restoration treatments, including fertilization. There was some evidence, however, that the increase in mortality rates for *V. scoparium* transplants that began with the droughty fourth season after transplanting was attenuated to a degree on the plots with amended soils. More research on soil amendments and transplanting success for *V. scoparium* is warranted, given the importance of the shrub in these forests and the difficulty of establishing it.

Growth of transplants was greatest in the second through fourth years after transplanting; mean transplant area declined over the final three years of the experiment. Although this temporal pattern was present regardless of treatment, it was most pronounced on the plots with compost and organic amendments. The fact that this pattern was exhibited on unamended plots suggests that it may reflect either climatic variability (the final three summers were considerably hotter and drier than early summers) or a temporary effect of the general restoration treatments, such as a reduction in soil compaction or competition. The more pronounced effect on plots with organics and with compost and organics suggests that this pattern reflects more than climate. Clearly, some of the restoration treatments had positive effects on plant growth that attenuated with time.

Surprisingly, the mulch treatment had little effect on transplanting success. Biodegradable mulches have been recommended because they decrease water loss, moderate soil temperatures, stabilize the soil surface, and provide protection from frost and herbivores (Urbanska and Chambers 2002). If their primary value is to decrease water loss, lack of effect may reflect the fact that the mulch had largely disintegrated within two years; transplants were given supplemental water the first year after transplanting, and the second summer was relatively cool and moist. Fattorini (2001) reported that mulch mats on ski runs on the Alps had no effect on transplant survival. Their primary affect was a reduction in flowering.

In conclusion, scarification of soils to break up compaction and transplanting locally collected plants is an effective means of accelerating the restoration of damaged campsites. However, the more elaborate treatments we experimented with were only modestly successful in increasing transplanting success. The application of a biodegradable mulch mat had no effect on success. The incorporation of organic material and native soil inoculum into the soil usually increased plant growth, but results were variable enough to seldom be statistically significant at a fixed alpha level of 0.05. Without a larger sample, we cannot confidently draw conclusions about the beneficial effects of this treatment.

Amendments with compost, in addition to organic matter and soil inoculum, increased growth further. Moreover, positive effects were large and consistent enough to be confident that they resulted from treatments rather than chance. However, these positive effects diminished over time, suggesting that their long-term effect may be negligible. Moreover, the plants that were most positively affected by soil amendments were graminoids, plants that survived and grew well on the unamended plots. The most challenging obstacle to restoration of a native groundcover on these sites is the high mortality rate and slow growth rate of the shrubs *Vaccinium scoparium* and *Phyllodoce empetriformis.* Identification of treatments that can overcome this obstacle is a critical research need.

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